Motor evoked potentials in unilateral lingual paralysis after monohemispheric ischaemia

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Abstract

***Objectives*—The occurrence of a lingual paralysis after unilateral upper motor neuron lesions is an infrequent clinical phenomenon, and the underlying pathophysiological mechanisms are poorly understood. We studied the cortical motor representations of ipsilateral and contralateral lingual muscles in healthy controls and in a selected group of stroke patients, to clarify the variable occurrence of a lingual paralysis after recent monohemispheric ischaemia.**

***Methods*—A special bipolar surface electrode was used to record the ipsilateral and contralateral compound muscle action potentials (CMAPs) from the lingual muscles after transcranial magnetic stimulation (TMS) of the human motor cortex and peripheral electrical stimulation (PES) of the hypoglossal nerve medial to the angle of the jaw. Four patients with a lingual paralysis (group 1) and four patients with symmetric lingual movements (group 2) after monohemispheric first ever stroke were studied and compared with 40 healthy controls.**

***Results*—In controls, TMS of either hemisphere invariably produces CAMPs in the ipsilateral and contralateral lingual muscles, elicited through crossed and uncrossed central motor pathways, respectively. In the 40 healthy controls, TMS of either hemisphere elicited CMAPs of significantly greater amplitudes and shorter onset latencies from the contralateral muscles compared with the ipsilateral responses ($p<0.0001$). In the patient groups, TMS of the affected hemisphere failed to evoke any CMAP from either lingual side; TMS of the unsevered hemisphere always produced normal ipsilateral and contralateral responses, irrespective of whether the ipsilateral muscles were paralysed or not.**

***Conclusions*—Bilateral crossed and uncrossed corticonuclear projections are invariably existent in humans. After unilateral interruption of these pathways, some people do exhibit a lingual paralysis whereas others do not. The development of a central lingual paralysis is most likely dependent on the ability of the unsevered hemisphere to utilise the pre-existent uncrossed motor projections. The variable availability of these pathways among individual subjects is in good agreement with the inconstant occurrence of a lingual paralysis after restricted monohemispheric lesions.**

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The occurrence of a unilateral lingual paralysis is usually ascribed to a lesion of the hypoglossal nerve or its nucleus within the brainstem. Unilateral upper motor neuron lesions are rarely mentioned according to the models of a bihemispheric, symmetric central innervation.[1–3] However, a unilateral lingual paralysis can be the presenting feature of a restricted monohemispheric lesion.[4–7] The underlying pathophysiological mechanisms are not fully understood, as the exact patterns of central innervation have not yet been fully elucidated. The models of symmetric central innervation cannot explain this phenomenon, as a symmetric innervation should provide a symmetric lingual function after unilateral loss of cortical control. A centre for controlling ipsilateral and contralateral lingual movements located in the dominant hemisphere[2 3] also seems unlikely, as a lesion of this centre would lead to a bilateral and symmetric paralysis of the lingua, whereas a lesion of the non-dominant hemisphere should not be clinically apparent.[7] This supports a model of an asymmetric rather than symmetric central innervation and gives rise to the question whether each hypoglossal nucleus is under an asymmetric control of both hemispheres, or exclusively under control of the contralateral hemisphere.

The present study aims to assess the patterns of central innervation to clarify the mechanisms of a central lingual paralysis after a monohemispheric lesion by using functional testing with transcranial magnetic stimulation (TMS) of the motor cortex and peripheral electrical stimulation (PES) of the hypoglossal nerve medial to the angle of the jaw. Transcranial magnetic stimulation of the human motor cortex is a non-invasive tool to assess the functional integrity of the fast conducting central motor pathways.[8 9] A single magnetic stimulus evokes responses in limb muscles and in muscles supplied by cranial nerves.[10–16] The lingual muscles have been shown to be easily excited by magnetic stimulation of the motor cortex.[6 12] Forty healthy controls and a selected group of eight patients with monohemispheric stroke were investigated in the present study using a distinct stimulation and recording procedure.

Subjects, patients, and methods

HEALTHY CONTROL SUBJECTS AND PATIENTS

Forty healthy subjects (20 men, 20 women; 20 right handed, 20 left handed) with a mean age of 39 (range 23–77) years and eight patients (four men, four women) with a mean age of 67 (range, 47–78) years volunteered with informed consent for the experiments. Inclusion criteria were: (1) monohemispheric, first ever stroke; (2) Cerebral

MRI or CT documenting the restricted unilateral hemispheric lesion; (3) bilateral absent responses after TMS of the severed hemisphere; (4) presence of a lingual paralysis (four patients, group 1), absence of a lingual paralysis (four patients, group 2).

The patients underwent physical and neuroradiological examination at the time of the TMS study in the scope of the usual diagnostic procedure. A unilateral lingual paralysis was defined as being present, when the tip of the protruded tongue repeatedly deviated more than 10 mm from the midline. Exclusion criteria were large hemorrhagic infarction, severe neurological diseases other than stroke, epileptic seizures, sinus-caroticus syndrome, patients after neurological surgery, patients with a cardiac pacemaker, and patients with dementia, severe aphasia, or cognitive disturbances making them unable to follow instructions or to give informed consent. The handedness was assessed using the Edinburgh handedness inventory.[17]

STIMULATION AND RECORDING PROCEDURE

The exact stimulation and recording technique has been described in detail previously.[6] To stimulate the hypoglossal nerve medial to the angle of the jaw, a high voltage low output impedance stimulator (Digitimer D180A, maximal output 1500 V, decay time of 50 μs) and bipolar pad electrodes soaked in saline with an interelectrode distance of 1.5 cm were used. Adhesive ground electrodes were placed on both cheeks. The stimulus strength was increased stepwise up to a supramaximal intensity.

The motor cortex was excited by a magnetic stimulator (MagLite, Dantec) with a maximum output voltage of 1.8 kV and a peak magnetic field of 1.9 Tesla according to the manufacturer's specifications. A focal figure of eight stimulus coil of 60 mm mean diameter each wing (MC B70, Dantec) was used for a detailed map of ipsilateral and contralateral cortical motor representations, and to assess the influence of various stimulus intensities and the amount of voluntary preinnervation on CMAP amplitudes and latencies in a control subject. A circular coil of 70 mm mean diameter (MC 125, Dantec) was used in the 40 healthy controls to establish normative data, and for the investigations performed in the two patient groups. The coils were always held in the same direction with the handle pointing occipitally, and held parallel to the midsagittal line. When TMS of the affected hemisphere failed to elicit any CMAP in the patient group, the stimulus intensitiy was increased up to the maximal stimulator output.

Simultaneous surface recordings from both sides of the lingual muscles were taken with two pairs of silver-silver chloride disc electrodes at a longitudinal and lateral between electrode distance of 25 mm and 20 mm respectively. They were fixed in arrangement, and embedded in a polyvinyl chloride mouthpiece adapted to the oral cavity. The mouthpiece was placed on the upper surface of the lingua, and the subjects were asked to hold the end of the mouthpiece between their teeth while closing their lips, and to push the lingua tightly against the electrodes and their lower teeth. The four electrodes were connected to the amplifier to allow synchronous bipolar registration of ipsilateral and contralateral CMAPs from either lingual half.

The responses were amplified and recorded with a Dantec Counterpoint MK 2 system with bandpass filter from 3 Hz to 6 kHz. At least four subsequent responses were recorded for further analysis. The latencies were measured to the first negative deflection from the baseline, and the amplitudes were evaluated peak to peak. As the ipsilateral and contralateral CMAPs after TMS showed the inherent variation typical of cortically evoked responses, the shortest reproducible latency and the greatest amplitude out of at least four responses were taken for evaluation.

DATA ANALYSIS

The following parameters were analysed: (1) distal latency and amplitude of the CMAP after peripheral elictrical stimulation of the hypoglossal nerve medial to the angle of the jaw; (2) ipsilateral and contralateral corticomuscular latency and amplitude of the CMAP after TMS; (3) crossed and uncrossed corticoangular conduction time (CACT), which was calculated by substracting the distal latency from the corticomuscular latency.

STATISTICAL ANALYSIS

Amplitudes, latencies, and corticoangular conduction times were assessed by analysis of variance (ANOVA). The grouping factor was handedness and sex. Age was dichotomised above and below the median of 35.5 years. The within subject factors were stimulation side and recording side. The analysis was conducted using statistical analysis system SAS version 6.12 for Windows, general linear model (GLM) program. All p values were considered significant if <0.05.

Results

The bipolar surface electrode with two separate pairs for each side of the lingua usually allowed separate CMAP recordings without major interference from the other lingual side. Occasionally, PES of the hypoglossal nerve also elicited responses in the contralateral lingual muscles, despite a careful positioning of the mouthpiece in the midline. These responses showed a sharp initial negative deflection from the baseline and were of identical onset latencies compared with the ipsilateral responses. The contralateral amplitude usually remained below 20% except for one subject, in whom it reached 64% of the ipsilateral CMAP amplitude. Likewise, a similar crossover of the response from one side to the other seems possible after TMS. Thus the ipsilateral responses after TMS may partially be derived from the contralateral lingual side in these cases, thereby misrepresenting CMAPs solely propagated via the uncrossed corticonuclear projections. However, to provide an appropriate estimation of these pathways, a peripheral crossover of the CMAP must be excluded after cortical stimulation.[18] As a consequence, subjects with bilateral identical onset latencies after TMS were not included in this series, when a

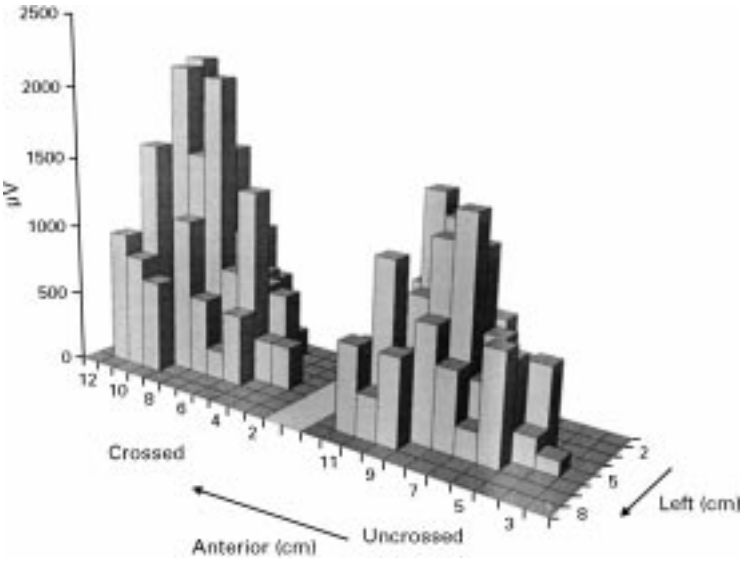

Figure 1 Amplitudes of the CMAPs elicited via crossed and uncrossed cortical projections by transcranial magnetic stimulation of the left hemisphere in a control subject. Each bar represents the average value of four subsequent CMAP amplitudes. The position of the centre of the coils (intersection of the wings) relative to the vertex is indicated.

peripheral crossover was obvious after PES (six subjects).

OPTIMAL COIL POSITION (CIRCULAR COIL, FIGURE OF EIGHT COIL)

For motor cortex stimulation, the optimal positioning of the circular coil was evaluated by mapping 72 stimulation points over the scalp. The centre of the coil was moved in steps of 10 mm over the hemisphere so as to make the 70 mm diameter coil roughly cover the primary motor fields of the tongue.[19] With a constant stimulus intensity (50% of the maximal stimulator output) with the current in the coil flowing counterclockwise as viewed from above for the left hemisphere and vice versa, a mean amplitude from four responses was determined for each stimulation point. The optimal position was defined as the one in which TMS elicits CMAPs of maximal amplitude in the ipsilateral and contralateral target muscle and was found when the coil was centred between 0 cm and 4 cm anterior and 4 cm to 6 cm laterally of the vertex. Coexcitation of the contralateral hemisphere was ruled out by moving the stimulus coil from the optimal stimulation site gradually to the vertex using a constant stimulus intensity (50% of the maximal stimulator output). Stimulation near the midline did not induce CMAPs on either lingual side.

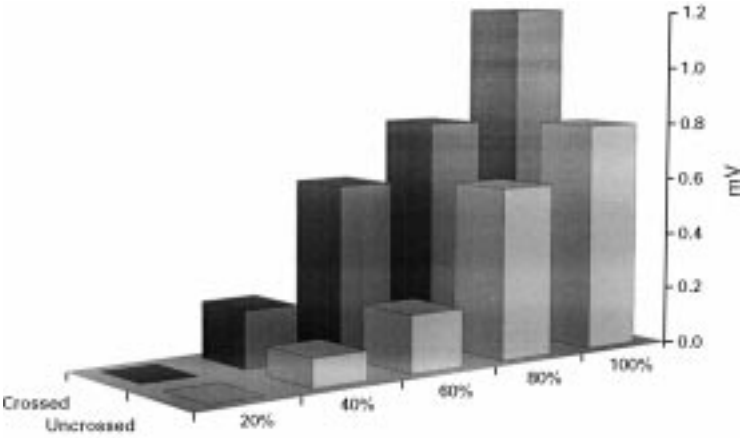

Figure 2 Amplitudes of the CMAPs elicited in the right (dark bar) and left (bright bar) lingual muscle by transcranial magnetic stimulation of the left hemisphere are related to different stimulus intensities (% of maximum stimulator output). Each bar represents the average value of eight subsequent responses.

To assess the ipsilateral and contralateral cortical motor output patterns, a detailed map was performed with a more focal figure of eight coil by stimulating 96 points over the left hemisphere in a control subject. With a constant stimulus intensity (50% of the maximal stimulator output), a mean amplitude from four responses was determined for each stimulation point. Figure 1 illustrates the map of crossed and uncrossed cortical motor projections of the left hemisphere in a healthy control subject.

STIMULUS INTENSITY AND VOLUNTARY BACKGROUND INNERVATION (FIGURE EIGHT COIL)

At the optimal coil position, the influence of different stimulus intensities on ipsilateral and contralateral CMAP latencies and amplitudes was assessed in a control subject. A stimulus intensity of 35% was sufficient to evoke more than three CMAPs out of five stimuli in the contralateral lingual muscles, but was not sufficient to produce more than two responses from the ipsilateral side. By contrast, ipsilateral and contralateral CMAPs were readily obtained by increasing the stimulus intensity in steps of 5% up to the maximum stimulator output.

The average CMAP amplitude and latency out of eight responses was determined for a stimulus intensity of 20%, 40%, 60%, 80%, and 100% of the maximum stimulator output. Increasing the stimulus intensity led to shorter CMAP onset latencies and to greater CMAP amplitudes bilaterally (fig 2). The average decrease in onset latency by increasing the intensity from 40% to 100% of the maximal stimulator output was 2.1 ms and 1.4 ms for the crossed and uncrossed responses, respectively. With a stimulus intensity of 60% and 70%, CMAPs with 50% of the maximal CMAP amplitude were obtained from the contralateral and ipsilateral lingual muscles, respectively. The contralateral responses showed greater CMAP amplitudes and shorter onset latencies compared with the ipsilateral responses at various stimulus intensities.

The influence of the amount of voluntary background preinnervation on ipsilateral and contralateral CMAP amplitude and latency was assessed at various preinnervation levels in a control subject. The proband was asked to hold the mouthpiece between his teeth while closing his mouth, and to push the tongue with maximal effort (100%) against the electrodes and his lower teeth during cortical stimulus application. The subject was then asked to reduce the activity to roughly 75%, 50%, and 25% of the maximal voluntary activity. An online rectified visual and an acoustic EMG signal served as feedback for the amount of voluntary muscle activation.

The average CMAP amplitude and latency out of eight stimuli were determined for each level of activation. Increasing the background preinnervation led to greater CMAP amplitudes and shorter onset latencies, but a

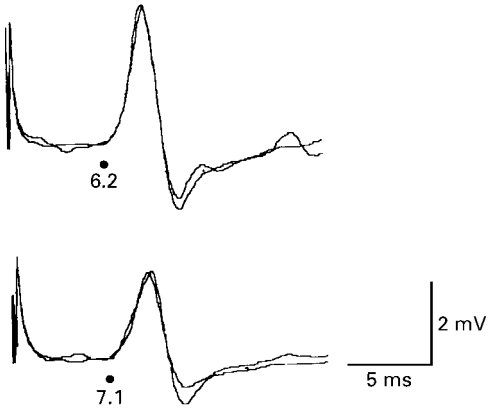

Figure 3 Motor evoked potentials recorded from the left (upper traces) and right (lower traces) lingual side after transcranial magnetic stimulation of the right hemisphere in a control subject. The numbers indicate the the latencies of the CMAP onset in ms (two responses superimposed).

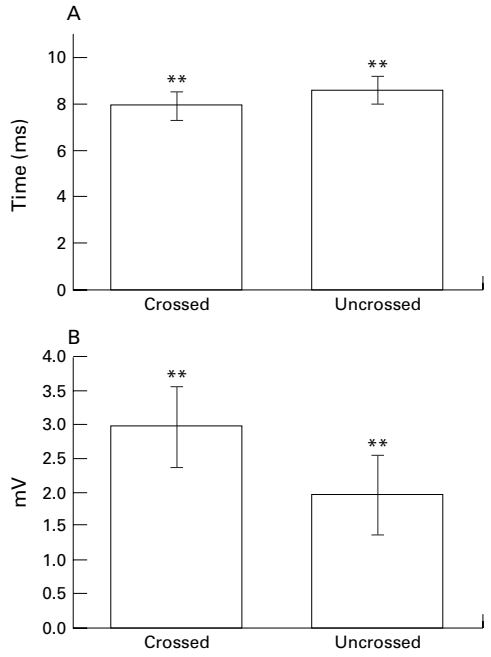

Figure 4 Crossed (left) and uncrossed (right) corticomuscular latency (A) and CMAP amplitude (B) evoked by transcranial magnetic stimulation of the motor cortex in 40 control subjects. Each bar represents the average value of 80 responses; error bar=SD

preinnervation above 75% of the maximal activity made identification of the exact CMAP onsets difficult due to the sizeable background EMG activity. The average decrease in CMAP onset latency by increasing the voluntary activity from 25% to 75% of the maximal activity was 1.4 ms and 1.0 ms for the crossed and uncrossed projections, respectively. CMAPs with amplitudes up to 50% of the maximal CMAP amplitude were obtained at preinnervation levels of roughly 25% and 50% for the crossed and uncrossed motor projections, respectively. The contralateral responses showed greater CMAP amplitudes and shorter onset latencies compared with the ipsilateral responses at various preinnervation levels.

HEALTHY CONTROLS

In the 40 healthy controls, cortical stimulation of either hemisphere invariably produced ipsilateral CMAPs with amplitudes averaging roughly 70% of the contralateral responses, and in five subjects the maximal amplitude was even greater on the ipsilateral lingual side. Figure 3 illustrates typical ipsilateral and contralateral CMAPs evoked after TMS of the right hemisphere in a control subject. The average crossed corticomuscular latency in the control group was 7.9 (SD 0.83) ms (range 6.4 ms-10.0 ms) and the average uncrossed latency was 8.6 (SD 1.30) ms (range 6.9 ms-12.5 ms). The average crossed amplitude was 3.0 (SD 1.40) mV (range 1.2 mV-9.3 mV) and the average uncrossed amplitude was 2.0 (SD 0.90) mV (range 0.5 mV-5.1 mV). The responses elicited in the contralateral lingual side showed a significantly greater mean CMAP amplitude (fig 4 B), a shorter mean onset latency (fig 4 A), and a shorter mean corticoangular conduction time when compared with the ipsilateral responses ($p<0.0001$). There were no significant differences in CMAP amplitudes and latencies for age, sex, handedness, or stimulation side after TMS or PES ($p>0.05$). The upper and lower limits of normal for distal latency, ipsilateral, and contralateral corticomuscular latencies, corticoangular conduction times, and CMAP amplitudes were defined as the average values ±2 SD, respectively. Table 1 summarises the latencies, conduction times, and amplitudes of the CMAPs obtained after TMS and PES in 40 control subjects (80 sides).

Table 1 Motor evoked potentials from lingual muscles in 40 control subjects (80 sides)

	Stimulus site					
	Angular right	*Angular left*	*Cortical left*	*Cortical left*	*Cortical right*	*Cortical right*
Recording side	Right	Left	Right	Left	Right	Left
Latency (ms):						
Range	2.0–3.3	1.9–3.1	6.4–10.0	6.9–12.5	6.9–12.0	6.5–9.4
Mean (SD)	2.3 (0.32)	2.2 (0.24)	7.9 (0.92)	8.7 (1.29)	8.5 (1.31)	8.0 (0.73)
Amplitude (mV):						
Range	3.8–19.8	2.2–14.0	1.3–9.3	0.8–4.2	0.5–5.1	1.2–7.4
Mean (SD)	8.9 (3.24)	8.3 (2.61)	3.2 (1.49)	2.0 (0.84)	2.0 (1.0)	2.8 (1.30)
CACT (ms):						
Range			3.6–7.8	4.4–10.2	4.3–9.9	4.1–7.3
Mean (SD)			5.7 (1.06)	6.5 (1.32)	6.3 (1.45)	5.8 (0.74)
Relative amplitudes (%):						
Range			11.6–100	8.5–89.4	5.0–72.9	14.8–100.0
Mean (SD)			38.8 (20.31)	27.6 (16.37)	24.5 (15.0)	37.7 (21.89)

CACT = corticoangular conduction time.

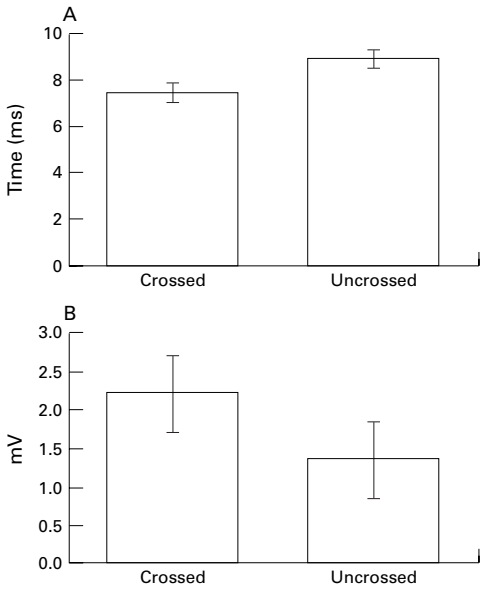

Figure 5 Crossed (left) and uncrossed (right) corticomuscular latency (A) and CMAP amplitude (B) evoked by transcranial magnetic stimulation of the unsevered hemisphere in the eight patients. Each bar represents the average value of eight responses; error bar=SD.

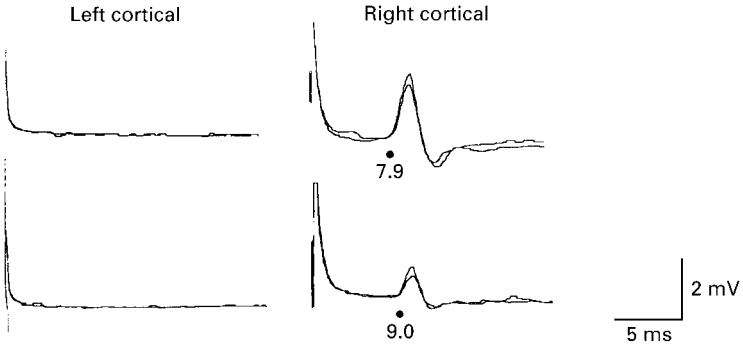

Figure 6 Motor evoked potentials from the left (upper traces) and right (lower traces) lingual side after transcranial magnetic stimulation of the left (left traces) and right (right traces) motor cortex in patient No 2 with a left hemispheric ischaemia. The numbers indicate the the latencies of the CMAP onset in ms (two responses superimposed).

PATIENTS

The eight patients showed a monohemispheric ischaemia as confirmed by CT. In four patients, a deviation of the lingua was present, and was always directed towards the side of the hemiparesis (group 1). By contrast, a symmetric lingual function was obvious in the remaining four patients (group 2). The average time interval between the stroke and the electrophysiological investigation was 10 days, ranging from 1 to 30 days after the acute event. In both patient groups, TMS of the affected hemisphere failed to evoke any response from either lingual side despite maximal stimulus intensities. Stimulating the unsevered hemisphere always disclosed normal ipsilateral and contralateral responses. The average CMAP amplitude and the average corticomuscular latency of the patients after TMS of the unsevered hemisphere are illustrated in fig 5 A and B.

In the patients of group 1, the average crossed corticomuscular latency after TMS of the unsevered hemisphere was 7.0 (SD 0.42) ms (range 6.50 ms-7.50 ms) and the average uncrossed latency was 8.48 (SD 1.23) ms (range 7.10 ms-10.0 ms). The average crossed amplitude was 2.33 (SD 1.14) mV (range 1.20 mV-3.70 mV), and the average uncrossed amplitude was 1.30 (SD 1.0) mV (range 0.70 mV-2.80 mV). In the patients of group 2, the average crossed corticomuscular latency was 7.90 (SD 0.62) ms (range 7.40 ms-8.80 ms) and the average uncrossed latency was 9.03 (SD 0.80) ms (range 8.20 ms-9.80 ms). The average crossed amplitude was 2.10 (SD 2.35) mV (range 0.60 mV-5.60 mV) and the average uncrossed amplitude was 1.80 (SD 1.59) mV (range 0.60 mV-3.60 mV). Electrical stimulation of the hypoglossal nerve medial to the angle of the jaw (PES) always elicited normal responses bilaterally.

Figure 6 shows typical CMAPs evoked by TMS in a patient with a left cortical ischaemia who presented a deviation of the lingua to the right. Table 2 gives the latencies, amplitudes and the corticoangular conduction times of the CMAPs elicited from the lingual muscles by PES and TMS for each of the eight patients.

Table 2 Motor evoked potentials from lingual muscles

		Angular stimulation			*Crossed responses*			*Uncrossed responses*		
Patient No (sex, age)	*Lingual paralysis*	*Recording side*	*Latency (ms)*	*Amplitude (mV)*	*Latency (ms)*	*Amplitude (mV)*	*CACT (ms)*	*Latency (ms)*	*Amplitude (mV)*	*CACT (ms)*
1 (F, 75)	Yes	Right	2.0	8.2	7.1	3.7	5.1	NR*	NR*	NR*
		Left	2.4	6.8	NR*	NR*	NR*	8.8	2.8	6.4
2 (F, 67)	Yes	Right	2.0	2.9	NR*	NR*	NR*	8.0	0.9	6.0
		Left	2.2	6.0	6.9	2.8	4.7	NR*	NR*	NR*
3 (F, 47)	Yes	Right	2.2	6.1	6.5	1.2	4.3	NR*	NR*	NR*
		Left	2.0	9.1	NR*	NR*	NR*	7.1	0.8	5.1
4 (M, 63)	Yes	Right	2.2	5.6	7.5	1.6	5.3	NR*	NR*	NR*
		Left	2.4	5.1	NR*	NR*	NR*	10.0	0.7	7.6
5 (M, 77)	No	Right	2.4	4.3	NR*	NR*	NR*	10.4	0.3	7.8
		Left	2.6	5.2	7.8	0.6	5.2	NR*	NR*	NR*
6 (F, 78)	No	Right	2.6	4.2	NR*	NR*	NR*	9.1	0.6	6.5
		Left	2.4	3.1	7.6	1.3	5.2	NR*	NR*	NR*
7 (M, 77)	No	Right	2.6	2.6	NR*	NR*	NR*	9.8	1.2	7.2
		Left	2.8	3.8	8.8	0.9	6.0	NR*	NR*	NR*
8 (M, 58)	No	Right	2.7	6.4	7.4	5.6	4.7	NR*	NR*	NR*
		Left	2.6	7.4	NR*	NR*	NR*	8.2	3.6	5.6

*Abnormal response. CACT=corticoangular conduction time.

Discussion

The occurrence of a unilateral lingual paralysis after a restricted monohemispheric lesion has been reported previously.[4–7 16] The pathophysiology of this infrequent and inconstant clinical phenomenon is still a matter of discussion, as the exact patterns of central innervation of the lingua are not well elucidated yet. The presence of a lingual paralysis after a restricted lesion of the contralateral hemisphere is evidence of an asymmetric rather than symmetric central innervation and gives rise to the question whether each hypoglossal nucleus is under the control of both hemispheres or exclusively under control of the contralateral hemisphere. Unilateral lingual seizures due to focal epileptic cortical discharges[20–22] and the existence of a unilateral opercular syndrome[23] suggest unilateral corticonuclear projections. By contrast, unilateral stereotaxic stimulation studies of the motor cortex[24] or of the capsula interna[25 26] induced bilateral movements of the lingua, pointing to bilateral corticonuclear projections. This was also shown with non-invasive TMS of the motor cortex in humans, as stimulation of either hemisphere produces CMAPs in the contralateral and ipsilateral lingual muscles.[6 7 14 15 27]

The invariable existence of bilateral corticonuclear projections in humans was confirmed in the present study with a circular coil and by using a more focal figure of eight stimulating coil. As a relevant coexcitation of the contralateral hemisphere was excluded, and as a crossover of the CMAP from one lingual side to the other was ruled out, the contralateral and ipsilateral responses could be identified as CMAPs elicited through crossed and uncrossed central motor pathways, respectively.

At very low stimulus intensities, contralateral but not ipsilateral CMAPs were obtained. Increasing the stimulus intensity invariably produced ipsilateral and contralateral CMAPs. The contralateral responses showed greater CMAP amplitudes and shorter onset latencies when compared with the ipsilateral responses, irrespective of the coil position, stimulus intensity, or amount of voluntary preinnervation of the target muscles. In the 40 healthy controls, important ipsilateral central innervation was found, and in five subjects, even greater responses were evoked when stimulating the ipsilateral hemisphere. Nevertheless, the average amplitude of the CMAPs was significantly greater and the average corticomuscular latency and corticoangular conduction time was significantly shorter when elicited through crossed projections compared with the uncrossed responses ($p<0.0001$). These findings are further evidence of the existence of crossed and uncrossed corticonuclear projections to the lingual muscles in humans and indicate that the crossed projections seem to be stronger in most people.

This assumed functional dominance of the crossed projections in voluntary activation of the lingua was clinically obvious in the four patients of group 1 who presented a unilateral lingual paralysis after their monohemispheric ischaemia. Transcranial magnetic stimulation of the affected hemisphere failed to evoke any CMAP from either lingual half. Cortical stimulation of the unsevered hemisphere elicited smaller responses of longer onset latencies from the paretic side compared with the responses obtained from the contralateral muscles. Although the apparent asymmetry in lingual function was paralleled by an asymmetric CMAP pattern, it is doubtful whether these electrophysiological findings are causally related to the clinical symptom. In fact, the differences in CMAP amplitudes and latencies alone can not fully explain the development of a unilateral lingual paralysis, as similar CMAP differences were found in the patients with preserved lingual function. Only one patient showed an inversed pattern of ipsilateral and contralateral CMAP amplitudes (patient No 7), but again this patient presented the typical CMAP latency differences found in group 1 and in the healthy controls. Nevertheless, the ipsilateral CMAP amplitudes and latencies were in the normal range in both patient groups, irrespective of whether the ipsilateral muscles were paralysed or unaffected.

The preserved cortical responses on the paretic side of the lingua after stimulation of the unaffected ipsilateral hemisphere is good evidence for the existence of uncrossed pathways that were voluntarily inaccessible during the acute stage of the disease in the patients of group 1. Similar discrepancies between voluntarily and transcranially evoked muscle activation have also been found in traumatic spinal lesions, motor neuron diseases and in cerebrovascular disorders, where no voluntary activation was possible but muscle activity could be evoked by reinforcement manoeuvres and by transcranial magnetic or electrical stimulation of the motor cortex.[28–31] By contrast, it is not likely that the uncrossed pathways are generally inaccessible during the acute stage of the disease, as the great majority of patients with hemispheric lesions might be expected to exhibit a lingual paralysis under these conditions. This was shown to be the case in the patients of group 2 with preserved lingual function, in whom TMS of the affected hemisphere failed to evoke any CMAP. Therefore, the preserved lingual function must be issued from the unsevered hemisphere in these cases, hereby proving the functional integrity of the uncrossed corticonuclear projections.

In summary, it has been shown that bilateral crossed and uncrossed corticonuclear projections are invariably existent in humans. After unilateral interruption of these pathways, some patients do exhibit a lingual paralysis, whereas others do not. The development of a central lingual paralysis is most likely dependent on the ability of the unsevered hemisphere to utilise the pre-existing uncrossed motor projections. The variable availability of these pathways among subjects is in good agreement with the inconstant clinical phenomenon of a lingual paralysis after a restricted monohemispheric lesion.

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